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History of Lasers in Dermatology

Michael L. Geiges

Institute and Museum of Medical History, University of Zurich and Department of Dermatology, University Hospital Zurich, Zurich, Switzerland

Abstract

In the 1950s, based on the theory of stimulating radiant energy published by Albert Einstein in 1916, the collaboration of physicists and electrical engineers, searching for monochromatic radiation to study the spectra of molecules, led to the invention of the first laser in 1960. Ophthalmologists and dermatologists were the first to study the biological effects and therapeutic possibilities of laser beams. The construction of new laser systems emitting energy at different wavelengths or with different durations, as well as the development of new concepts of the biomedical effects, led to its broad use in surgery in the treatment of vascular and pigmented lesions as well as cosmetic applications.

It was not predictable that an analytical tool for physicists to examine the molecular structure of molecules would become one of the most important inventions of the 20th century. Theodore Maiman was enthusiastic about the first laser he constructed, but regarded it as 'a solution looking for a problem' [1]. The expectations during the Cold War that lasers could be used as powerful weapons remained unfulfilled. Nonetheless, today laser systems are present in almost every household, at least in CD players. The acceptance of lasers in medicine by doctors as well as by patients has always been very high. With a positive attitude towards such a powerful source of harmless-looking light, lasers became regarded as magic bullets for the treatment of cancer, replacing the bloody knife of the surgeons.

The history of laser is very young and tells of an invention of great economic value. However, this makes it very difficult to interpret the different references, which are predominantly scientific papers and autobiographical retrospections of the people involved. Depending on the intention and the background of the authors, selection and emphasis vary.

Inventing the Laser

In 1916, Albert Einstein discussed the possibility of stimulating radiant energy based on Niels Bohr's theory that atoms emitted energy in quanta when transitioning from excited states back to resting states [2]. The first experimental proof of his theory was published by the German physicists Rudolf Ladenburg and Hans Kopfermann in 1928 [3]. However, stimulated emission received little attention from experimentalists during the 1920s and 1930s when atomic and molecular spectroscopy were of central interest to many physicists [4]. In 1939, Valentin A. Fabrikant defended his doctoral thesis, 'The emission mechanism of a gas discharge', at the P.N. Lebedev Physical Institute in Moscow. It discussed experimental evidence for the existence of negative absorption (what was later called stimulated emission) and suggested experiments on light amplification [5].

Although the essential ideas for constructing a laser were known around 1930, it was not before the early 1950s that physicists and electrical engineers began to collaborate with the research on monochromatic radiation of constant amplitude at very small wavelengths studying the microwave and radio frequency spectra of molecules. In this context, in 1953 and 1954, several physicists independently suggested the use of stimulated emission for microwave amplification, creating the acronym MASER to stand for 'microwave amplification by stimulated emission of radiation' [6].

In 1953, the American physicist Joseph Weber at the University of Maryland published a proposal for a microwave amplifier that was based on stimulated emission in a paramagnetic solid [7]. In 1954, Nikola G. Basov and Alexander M. Prokhorov of the Lebedev Institute in Moscow and J.P. Gordon, H.J. Zeiger, and Charles H. Townes of Columbia University in New York reported on two molecular devices for generating microwave radiation, both using the ammonia molecule as the active species [8, 9].

Charles H. Townes, Nikolay G. Basov, and Alexander M. Prokhorov received the Nobel Prize in Physics 1964 for their 'fundamental work in the field of quantum electronics which has led to the construction of oscillators and amplifiers based on the maser-laser principle' [10].

The ammonia beam maser itself was not particularly useful as its operation was limited to the resonant frequency of the ammonia molecule and could only be used at barely detectable power levels [1]. In 1958, C.H. Townes and his brother-in-law Arthur Leonard Schawlow, professor at Stanford University, showed that masers could theoretically be made to operate in the optical and infrared regions [11]. The same year, G. Makov, C. Kikuchi, J. Lambe and R.W. Terhune at the University of Michigan developed and built a solid-state maser [12]. They used crystalline corundum (ruby) in a large magnetic field and a strategy similar to that known as optical pumping, suggested by Nicolas Bloembergen at Harvard University in 1956 [13]. Theodore H. Maiman at the Hughes Corporation Research Laboratories took over the Kikuchi ruby maser. In 1960, he presented the first functional optical ruby maser excited by a xenon flash lamp to produce a bright pulse of 693.7 nm, deep red light of about a 1-ms duration and a power output of about a billion watt per pulse [14]. His invention rapidly led to the development of multiple other optical masers, now called laser (light amplification by stimulated emission of radiation). In 1961, Fred J. McClung and Robert W. Hellwarth introduced the quality-switching (Q-switching) technique to shorten the pulse length to nanoseconds with the use of an electro-optical shutter that permitted the storage and subsequent release of a peak power up to gigawatts of energy [15, 16].

Medical Use of Lasers

The medical specialists who were already treating diseases with sunlight and technical light sources were also the first to carry out biomedical research with lasers.

One year after Maiman had presented the first ruby laser, ophthalmologists using xenon lamps for retinal photocoagulation published on ocular lesions experimentally produced in a rabbit by an optical maser [17]. These studies were soon followed by clinical experience on patients treated for retinal tears, flat detachments, angiomas, and tumors [18].

In dermatology, the treatment of skin diseases with light has a long tradition – e.g. lupus vulgaris with the Finsen lamp in 1899, wound healing and rickets with artificial UV light sources after

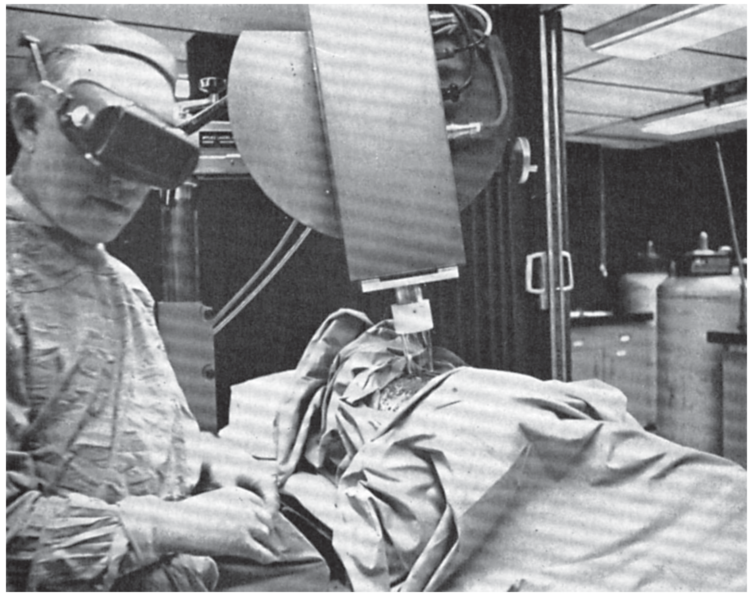

Fig. 1. Experimental treatment of metastatic cutaneous melanoma with a pulsed neodymium laser by Leon Goldman [23].

1901, and psoriasis with the combination of light and tar in 1925. Hence, it is no surprise that the American Society for Laser Medicine and Surgery honors a dermatologist, Leon Goldman, as the 'father of lasers in medicine in the United States' [19]. Leon Goldman did his dermatological training in Zürich, London, and Cincinnati. He was Chairman of the Department of Dermatology at the University of Cincinnati when he learned of the invention of Theodore Maiman's ruby laser in 1960. He was convinced of the great potential of lasers in medicine. In 1961, he founded the first biomedical laser laboratory at the University of Cincinnati [20]. In 1963, Goldman and his coworkers published the first study on the effects of lasers on skin describing the selective destruction of pigmented structures of the skin including hair follicles with the beam of the ruby laser. They noted highly selective injury of pigmented structures (black hair) with no evident change in the white skin underneath [21, 22].

Goldman published on the possible treatment of nevi, melanomas, and tattoos using the pulsed ruby laser: 'The most striking results have been obtained with the removal of tattoos, especially with the Q switched laser'. He expected the laser to bring substantial benefits to the treatment of skin cancer: 'Because of the accessibility and color, laser surgery can be used extensively in the field of skin cancer. The most significant treatments have been given for that black cancer of man, melanoma. Here, our laboratory has done laser operations even in delicate areas such as melanoma near the brain. It is too early to tell how permanent the effects will be. . .' [23] (fig. 1).

He preformed clinical and histopathological studies on vascular malformations with the argon laser. In 1973, Goldman published promising effects on angiomas with the continuous-wave neodymium:yttrium-aluminium-garnet (Nd:YAG) laser. His book *Biomedical Aspects of the Laser* published in 1967 is a comprehensive overview over the possibilities, problems, and ideas of the use of the laser in medicine at that time, also emphasizing the need for protection from laser energy. In addition, he discussed ideas of using the laser as a diagnostic tool (transillumination) to detect foreign bodies, hard tumors, or bone defects, and presented data on the use of laser in dentistry.

Photoexcision (the optical scalpel) was possible with continuous-wave lasers all invented in 1964; first the CO_2 laser, followed by the Nd:YAG-laser and then the argon laser. For the CO_2 laser, the color of the target area was not of any great significance and with an out-of-focus beam and larger spot size, hemostasis was also possible making it a helpful tool for surgery on vasculated organs (liver, oral mucosa, gynecology). Developments in fiber optics made it possible to transmit far-infrared laser beams, increasing the flexibility of CO_2 lasers for endoscopic surgery. The argon laser showed superior absorption by hemoglobin and was used for treating port wine stains and teleangiectasia of the face and early rhinophyma [24].

The early continuous-wave lasers emitted an uninterrupted beam of light that was effective in destroying the desired target, but also exposed the surrounding healthy tissue to laser energy for prolonged periods. The result of this collateral damage was unacceptably high rates of hypertrophic scarring and pigment alteration. The first attempt to minimize this nonspecific tissue injury involved making the continuous-wave lasers discontinuous or quasi-continuous by using a mechanical shutter to interrupt the beam of light. In the treatment of vascular lesions, the development of the tunable yellow light dye laser with the absorption peak closer to oxyhemoglobin than the early argon lasers reduced the risk of side effects. In 1996, the erbium (Er):YAG laser with a very short wavelength of 2,940 nm allowed a more superficial vaporization of tissue and was used together with CO_2 lasers for skin resurfacing. Very recently, the new technical concept of fractional photothermolysis was introduced. It received FDA approval in 2004 for skin resurfacing and in 2005 for the treatment of melasma [25].

Selective Photothermolysis

These developments support the common assumption that progress in medicine (and laser dermatology) depends mainly on new technology; however, technical progress reflects only one part of the history of the laser. Both acceptance of and interest in observations depends very much on the attitude of the involved persons. Even within the short history of lasers in medicine, the example of the pulsed laser systems shows how new ideas foster new use of old technology [26].

Leon Goldman wrote in 1967: 'There is every indication that Q-switched lasers will remain an important tool in the physicists' laboratories' [23]. Despite the various treatment possibilities that Goldman proposed and the encouraging results he published, there was an initial lack of interest in the development and support of the use of pulsed lasers by the government, industry, and the armed forces. Surgeons focused their interest on continuous rather than pulsed lasers [24]. The ruby laser was ineffective when used as an optical scalpel for cutting or coagulation, and when using high-energy pulses the effect became unpredictable because of cavitations (vapor bubbles). The attempts to use the pulsed Nd:YAG laser were not more successful as tissue fragments were spattered all over the operating room [26]. In the 1980s, the pulsed ruby laser was commercialized in Japan for the treatment of tattoos and pigmented lesions, while being abandoned in Europe and the USA where tattoo removal was performed by CO_2 laser vaporization [27].

With the flashlamp-pumped pulsed dye laser in the early 1980s, R. Rox Anderson and John A. Parrish from the Department of Dermatology at the Harvard Medical School in Boston developed the theory of selective photothermolysis that revolutionized the practice of cutaneous laser surgery [28]. The authors recognized that the collateral thermal damage in the surrounding tissue of the target chromophore resulted from prolonged exposure to the laser's energy. By the appropriate manipulation of wavelength and pulse duration, and in dependence upon the chromophore's relaxation time, therapeutic destruction could be maximized while minimizing thermal damage to the surrounding tissue [29].

The new theoretical understanding of the advantages of pulsed lasers led to a revival of the Q-switched lasers (ruby [30], alexandrite [31], Nd:YAG [32]) for the treatment of benign pigmented cutaneous lesions, especially for tattoo and hair removal [33]. More than 3 decades later, a nearly identical ruby laser to the one used by Goldman in 1963 became the first device approved by the FDA in 1989 for permanent removal of pigmented hair, and the Q-Switched Nd:YAG received FDA approval as a treatment modality for tattoos in 1991 [25, 26].

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Michael L. Geiges, MD
Institute and Museum of Medical History, University of Zurich
Hirschengraben 82
CH–8001 Zurich (Switzerland)
Tel. +41 634 20 19, Fax +41 634 23 49, E-Mail michael.geiges@mhiz.uzh.ch